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Seasonal Species Composition of Barnacle Larvae (Cirripedia: Thoracica) in Rhode Island Waters, 1977-1978

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16. ABSTRACT

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Comparison of results with existing literature reveals several significant findings. The bimodal release of *S. balanoides* larvae is unusual and may be in response to the phytoplankton dynamics of the year; however, the existence of distinct races of *S. balanoides* may also be a factor. Larvae of *B. venustus* predominate in the lower bay during the summer, yet this species is unreported in past studies. *B. improvisus* nauplii are more cold tolerant than previously reported. Comparison of findings with reported breeding patterns in Florida indicate significant differences in temperature responses between northern and southern populations.

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Seasonal species composition of barnacle larvae (Cirripedia: Thoracica) in Rhode Island waters, 1977-1978[1]

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Abstract. Cirripede larvae can occur year-round in temperate and tropical waters, often in significant numbers, yet the species composition of the '*Balanus* sp.' component is rarely studied. Weekly plankton samples were analyzed qualitatively for larval cirripede species and stage over a year (1977-1978) at two Rhode Island stations. Six species of larvae were found in Lower Narragansett Bay (≅30‰ salinity). *Semibalanus balanoides* and *Balanus balanus* have a single winter brood. *S. balanoides* is the predominant winter breeder with a minor release of nauplii in early December and major release in March followed by cyprids in mid-April. *B. balanus* populations release all larvae in March with cyprids in mid-April. *Balanus crenatus* is mainly a winter breeder, but has multiple broods; it does not breed in July-September when the water temperature is above 18°C. *Balanus venustus* is the predominant summer breeder, and larvae were observed from May through December (water >8°C). Larvae of *Chthamalus fragilis* and *Balanus eburneus* occur in low numbers from May-October. At the Pettaquamscutt River site (≅12‰ salinity), *Balanus improvisus* larvae predominate and early stage nauplii (I-II) occur in samples year round (0-27°C). Two peaks of later stage nauplii and cyprids occur in late spring (May) and early winter (Nov.-Jan.). Continued temperatures below 5°C or above 20°C appear to inhibit larval development.

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Introduction

Cirripede nauplii and cyprids persist year-round in both tropical and temperate coastal water zooplankton assemblages (Fish, 1925; Deevey, 1960; Reeve, 1964; Lonsdale and Coull, 1977; and others), yet a basic understanding of the species composition of the "*Balanus* sp." component of most Western Atlantic regions is lacking due to neglect or inability to further analyze plankton samples. Although the seasonal breeding cycle and larval occurrence of the boreo-arctic species *Semibalanus balanoides* and *Balanus balanus* are well-studied (Fish, 1925; Barnes and Barnes, 1954, 1976; Bousfield, 1954; Crisp, 1954, 1962; Barnes and Costlow, 1961), less is known about the larval biology of most tropical-temperate

species (Lang, 1977).

In this study the species and developmental stage were determined for barnacle larvae sorted from weekly plankton samples taken at a high salinity and low salinity station in the Narragansett Bay region of Rhode Island. Our goal was to confirm existing studies and provide new information on breeding patterns for common barnacle species of the region.

Methods

Beginning September, 1977, approximately weekly plankton samples were taken at the University of Rhode Island, Graduate School of Oceanography dock, West Passage of Lower Narragansett Bay (GSO). In December, a second sample site at Bridgetown Bridge, Pettaquamscutt River (BB) was included. Surface tows of approximately 10 minutes were collected, most often on falling tides, using a 0.5 meter diameter #10 mesh net (153 μm aperture). Surface temperature and salinity were measured at each collection. Studies were terminated in December, 1978.

Samples ($\cong$150 ml) were preserved in neutralized formalin and subsamples (5 ml) sorted until approximately 100 cirripede nauplii were isolated or the entire sample exhausted. Larvae were then identified to larval stage and species using recently devised keys (Lang, 1979, 1980).

Results

Salinity and Temperature

Salinity at GSO ranged from 27 to 32 °/₀₀ with a mean of 30 °/₀₀. At BB, extremes of 1 °/₀₀ at low tide (during spring melting of snow) to 17 °/₀₀ at high tide were recorded. For 95% of the data the normal range of salinities ranged from 7 to 15 °/₀₀ with a mean value of 12 °/₀₀.

Surface temperatures at GSO ranged from 23°C in August to freezing in February (Figure 1B). At BB, waters warmed and cooled more rapidly relative to the bay with peaks in July and August of 27°C.

Cirripede Larvae

Barnacle larvae occurred in every sample, although the relative abundance varied considerably. In some cases, complete sorting of the sample yielded less than 20 nauplii while in others, a single subsample contained 200-300 larvae. Of the seven species of nauplii identified, six were found at GSO (*Balanus balanus, B. crenatus, B. eburneus, B. venustus, Chthamalus fragilis, Semibalanus balanoides*) and the seventh species (*Balanus improvisus*) was restricted to BB. Results are plotted for the seasonal occurrence of larval species and stage for six species at GSO and *B. improvisus* at BB (Figure 1A).

At GSO, *S. balanoides* was observed as early as late November 1978 and mid-December 1977. Larvae of this species were predominant during January-February and also during March-April. Cyprids were very abundant in the mid-April sample.

Balanus balanus larvae were found only during a 45-day span between March and April. Percentage composition of weekly samples (with *S. balanoides* and *B.*

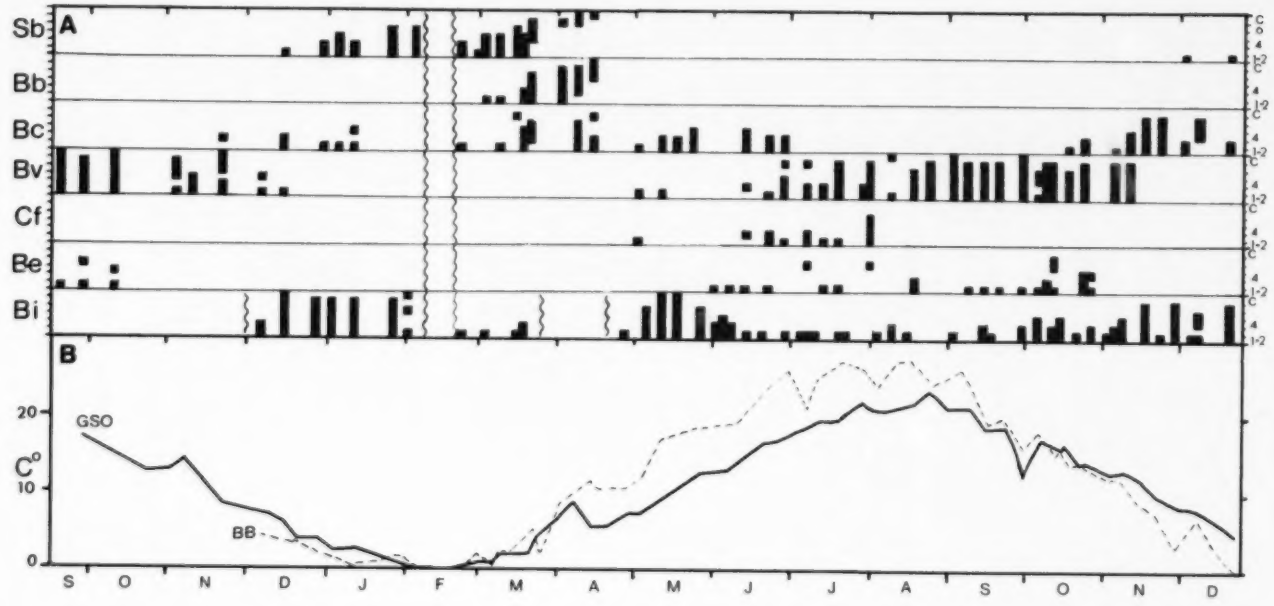

Fig. 1. Season occurence of cirripede larval stage and species (A) and surface water temperatures (B). Histogram bars indicate presence of naupliar stages 1-2, 3, 4, 5, 6 and cyprid (C) and day of collection ± 1.5d. Species are: *Semibalanus balanoides* (Sb), *Balanus balanus* (Bb), *Balanus crenatus* (Bc), *Balanus venustus* (Bv), *Chthamalus fragilis* (Cf), *Balanus eburneus* (Be) and *Balanus improvisus* (Bi). Bi samples are from BB sample site and the remainder from GSO (see text). A wavy line brackets periods of no samples.

crenatus) was less than 10%. A single progression to later stage nauplii over time was observed indicating one brood.

Balanus crenatus nauplii occurred in every month except July-September when water temperaures were >18°C. Later stage nauplii and cyprids occurred in March-April and November-December (1978). This species accounted for over 90% of the larvae in April and December, however, the actual number of larvae per sample at these times was consistently < 100 and in marked contrast to large numbers of larvae of other species evident in February-March (*S. balanoides*) and July-early September (*B. venustus*).

Balanus venustus nauplii were found during all months except January-April. Late stage nauplii and cyprids were evident during June-November. In late summer (August-early October) this species accounted for 85% of the larvae at GSO.

Chthamalus fragilis nauplii wre observed from May to early August, but generally in low numbers. In mid-July nauplii were common for two-weeks and comprised 40-70% of the nauplii in samples.

Balanus eburneus nauplii were found from September-October in 1977 and from June to October in 1978. Numbers were always low and occurrence of late stage nauplii was sporadic.

In the lower salinity water at BB, *Balanus improvisus* was the only adult species observed on intertidal rocks and was predominant on subtidal surfaces with some *B. eburneus* also present. Larvae at this station were nearly always 85-100% *B. improvisus* with some influx of *S. balanoides* and *B. crenatus* in the winter and low numbers (<10%) of *B. eburneus* in the summer. *B. improvisus* nauplii were found in every sample at BB, with low numbers in March and extremely dense concentrations in November-December. Nauplii beyond stage III were absent in late winter (February-April) as the number of stage II nauplii declined but were also conspicuously absent throughout the summer (mid-June-September) despite numerous stage I-II nauplii. Cyprids occurred sporadically in December-January and were common during late April and early May.

Discussion

The year-round occurrence of cirripede nauplii in Narragansett Bay results from populations of boreo-arctic species breeding in the winter and tropical-temperate species breeding in the summer. Using a #10 net, Hulsizer (1976) found the average weekly abundance of barnacle nauplii at a sample site near GSO to be 140-190/m^3 or 0.7-0.8% of the total zooplankton population. Peak abundance of nauplii in Narragansett Bay occur with the release of *S. balanoides* nauplii during January and February: 1100/m^3 (Frolander, 1955), 750/m^3 (Martin, 1965), 1900/m^3 (Hulsizer, 1976). During this period up to 15% of the total zooplankton population may be barnacle nauplii (Frolander, 1955). At other times of the year, occurrence of cirripede larvae is sporadic with nauplii most common in early fall (Faber, 1959; Haulsizer, 1976).

Breeding in *S. balanoides* occurs once a year and appears to be rather rigidly controlled by an endogenous process (Crisp and Patel, 1969). Following release of nauplii and a refractory period of no reproductive activity, slow conditioning and restoration of gonads occurs over the summer and fall. For European

populations, fertilization will occur following removal of a "temperature barrier" estimated to be about 10-12°C and larvae brooded during the winter. Release of nauplii in the spring is most often synchronized with diatom blooms (Barnes, 1957, 1962). In North America (NA), *S. balanoides* breeds earlier and embryonic development is more rapid relative to European populations (Crisp, 1968). Barnes and Barnes (1976) found NA populations north of Cape Cod tend to fertilize earlier with increasing latitude, while south of Cape Cod an "inversion" occurs and animals tend to fertilize earlier with decreasing latitude. The southern NA population appears to have a genetic component for early fertilization and brooding of larvae.

The release of nauplii in New England waters is not clearly documented in the literature. Fish (1925) found *S. balanoides* nauplii in Woods Hole plankton as early as December 16, 1922, but cyprids were not found until February 8, 1923. Fish (1925) also observed large quantities of nauplii on January 30 in Newport Harbor, Rhode Island, followed by abundant cyprids in March. Barnes and Barnes (1958) examined Woods Hole plankton samples and found nauplii in early December but cyprids were present 21 days later. They concluded larval development of *S. balanoides* in New England waters is complete in 21-23 days while at Halifax (Canada) development takes about 40 days. Bertrand (1977) noted nauplii from Penobscot Bay, Maine were abundant in early March followed by cyprids in late April.

Present results indicate release of *S. balanoides* in early December and a progression of later stages up to stage IV by late January. Samples in mid-February were curtailed by a severe blizzard; it is not known if stage VI and cyprids occurred in this interval. Continuation of samples in late February and early March revealed high concentrations of stage I and II nauplii. Stage VI nauplii were present 22 days later and cyprids were found by mid-April. A diatom bloom began March 2 this year with peak densities (6000 cells/ml) noted on March 16 (Murphy, personal communication). The apparent second release of nauplii coincided with this diatom outburst. The first naupliar release in early December and possible development to cyprids in February agrees with observations of Fish (1925). The second, more intense release of nauplii beginning in late February with larval development of about 40 days follows a pattern more typical for northern NA populations in Maine and Canada (Bousfield, 1954; Bertrand, 1977) and conforms to the classical account of synchronization with diatom blooms (Barnes, 1957).

Although local populations of *S. balanoides* often release larvae in one annual burst, Barnes (1956, 1957, 1962) notes cases where an initial ouput of nauplii, perhaps suppressed by a decline in diatom numbers, is subsequently followed by a second release of nauplii at a later diatom outburst. Thus a biomodal release of nauplii induced by environmental factors may occur in a local *S. balanoides* population and perhaps occurred in Narragansett Bay. The winter-spring diatom bloom of Narragansett Bay usually begins in December but may be delayed until late February (Pratt, 1965; Hulsizer, 1976). In 1978, the bloom was indeed exceptionally late and collapse of the initial naupliar release in December may have resulted (see also Barnes and Barnes, 1958).

The apparent differences in southern and northern NA *S. balanoides* population may also be a factor (Barnes and Barnes, 1976). If sets of both northern (late breeders) and southern (early breeders) populations contribute to the breeding adults in the Narragansett Bay, two different releases of nauplii may result.

Balanus balanus exhibits a long-term endogenous breeding cycle similar to *S. balanoides* (Crisp and Patel, 1969), with a single brood release in early spring in Europe (Crisp, 1954: Barnes and Barnes, 1954) and Canada (Bousfield, 1954). In agreement with these observations, *B. balanus* nauplii were first observed March 1 and progressed through cyprid by mid-April.

In contrast to the long-term and often endogenous nature of breeding cycles in *S. balanoides* and *B. balanus*, the remaining five cirripede species reported for Rhode Island will initiate and continue breeding in relatively rapid response to suitable temperature and nutrition (Crisp and Patel, 1969; Hines, 1978; Landau *et al.*, 1979).

Balanus crenatus is a boreo-arctic species with breeding inhibited above 17°C and embryonic development restricted to 3-18°C in laboratory studies (Crisp and Patel, 1969) and also predicted by field studies (Bousfield, 1954). A primary brood occurs in March-April with possible secondary broods in the United Kingdom, year-round broods occur in Central California, and a bimodal breeding season (May-June and September-October) occurs in New Brunswick (Bousfield, 1954; Hines, 1978). Results from Narragansett Bay are similar to observations by Bousfield (1954). Larvae were absent from waters above 18°C (July-mid-October) and two peaks of later stage nauplii were evident during March-April and November-December (1978). Fish (1925) reports "*B. crenatus* nauplii" as a single peak during early June to mid-July at Woods Hole. This is in marked contrast to other observations and perhaps represents a misidentification of *B. venustus* nauplii, a summer breeder (below) with previously undescribed larval stages (Lang, 1980).

Chthamalus fragilis cyprids settled from June to November at Beaufort, North Carolina with naupliar release most likely commencing in early to mid-May (14-17°C) (McDougall, 1943). Fish (1925) observed larvae of this species in only three samples at Woods Hole (July-August), despite adults being locally abundant. Similarly, nauplii were relatively uncommon in Narragansett Bay samples with the exception of a single peak in July. Present results infer a relatively restricted breeding period in mid-summer (15° – 22°C) with only one or two broods per season.

Balanus eburneus settled from late May to early December at Beaufort, North Carolina and commenced breeding at about 15°C (McDougall, 1943). Breeding in Long Island Sound is estimated to occur between 18-27°C (Landau *et al.*, 1979) and larvae occur from June to November at Woods Hole (Fish, 1925; Grave, 1933). At GSO nauplii first appeared June 1 and persisted sporadically until October at water temperatures above 14°C. Where in competition with *S. balanoides*, adults of *B. eburneus* are more common in lower salinity waters and, not unexpectedly, nauplii remained uncommon at the GSO station. Samples in an upper bay harbor would most likely yield more information on this species.

Although *B. venustus* is the most common subtidal barnacle of the Virginian

province (Zullo, 1979), little is known of its breeding habits. In South Carolina, nauplii occurred in low numbers year-round (Lang, 1977). In Narragansett Bay, nauplii first appeared May 1, with late stage nauplii and cyprids common from late June through mid-November. Breeding appears possible at 10°C or slightly below but most larvae occur at temperatures above 15°C. Continuous breeding during the summer and fall with relatively abundant larvae in September-October characterize this species.

Results at BB contrast sharply with those at GSO in that larvae of a single species (*B. improvisus*) occur year-round. This species is exceptionally euryhaline and often predominates in salinities less than 16 °/₀₀ with perhaps an optimal salinity range of 5-11 °/₀₀ (Bousfield, 1955; Gordon, 1969). The species also is eurythermal and occurs along the entire American coast (Zullo, 1979). Seasonal breeding of *B. improvisus* varies with geographic location and is reported to be inhibited below 10°C in its northern range (Canada) or above 27°C in its southern range (Florida) (Weiss, 1948b; Bousfield, 1954).

In the Miramichi Estuary (Canada) a first main brood occurs in May followed by a decline in larvae during July-August and a second main spawning in September-October (Bousfield, 1954). In Biscayne Bay (Florida) nauplii are most abundant from September to April with maximal settlement in March and October (Weiss, 1948a; Reeve, 1964; Moore *et al.*, 1975). McDougall (1943) found *B. improvisus* to settle in North Carolina during the winter from December to February (6-15°C) and Lang (1977) found nauplii in South Carolina during the same months at temperatures of 10-15°C. Branscomb (1972) noted one heavy set of cyprids during June in the Chesapeake Bay and subtidal adults containing developing eggs in March (probable temperature of 5-10°C).

Present results are surprising in that release of early stage nauplii (I-II) occurs year-round in a temperature range of 0-27°C. However, later stage nauplii are virtually absent in waters above 20°C and at 0-7°C following a month of near 0°C temperatures. Although a biomodal breeding pattern similar to that reported by Bousfield (1955) is evident, in contrast to his estimate of a lower thermal tolerance of 10°C, larvae are abundant in 2-5°C waters during December and January. Although late stage nauplii and cyprids are common from November to January, it appears unlikely that most larvae and spat will survive the winter. If so, successful repopulation of *B. improvisus* in Rhode Island is dependent on the spring larval outburst. Continual release of larvae occurs during the summer but nauplii fail to develop to later stages.

Rhode Island animals release nauplii at an extreme range of 0-27°C, however continual exposure to the extremes of this range appears to surpress breeding. Development to later stage nauplii and greatest concentrations of larvae occur at about 5-15°C. In sharp contrast, Florida populations are reported to normally breed at 18-27°C and, larvae from South Carolina adults complete development in laboratory cultures at 26°C (Lang *et al.*, 1979). However, attempts to rear Rhode Island nauplii at 23°C failed (unpublished results). These results further support Bousfield's (1955) contention that physiological races of *B. improvisus* exist.

Data in this study was restricted to planktonic occurrence of larvae in an em-

bayed situation. Although a relatively clear picture of seasonal breeding of cirripede species may be derived using this approach, ideally a study would incorporate both plankton data and quantitative observations of embryos in adult populations and, perhaps, observations on settling of spat. This latter approach should provide a comprehensive understanding of cirripede breeding cycles in a given estuary or region.

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References

Barnes, H.: 1956, '*Balanus balanoides* (L) in the Firth of Clyde: the development of annual variation of the larval population, and the causative factors'. *J. Animal Ecol.* **25**, 72-83.

Barnes, H.: 1957, 'Processes of restoration and synchronization in marine ecology. The spring diatom increase and 'spawning' of the common barnacle *Balanus balanoides* (L)'. *Annee Biol.* **33**, 67-85.

Barnes, H.: 1962, 'Note on variations in the release of nauplii of *Balanus balanoides* with special reference to the spring diatom outburst'. *Crustaceana* **4**, 118-122.

Barnes, H. and Barnes, M.: 1954, 'The general biology of *Balanus balanus* (L.) Da Costa'. *Oikos* **5**, 63-76.

Barnes, H. and Barnes, M.: 1958, 'The rate of development of *Balanus balanoides* (L.) larvae'. *Limnol. Oceanogr.* **3**, 29-32.

Barnes, H. and Barnes, M.: 1976, 'The rate of development of the embryos of *Balanus balanoides* (L.) from a number of European and American populations and the designation of local races'. *J. Exp. Mar. Biol. Ecol.* **24**, 251-269.

Barnes, H. and Costlow, J.D.: 1961, 'The larval stages of *Balanus balanus* (L.) Da Costa'. *J. Mar. Biol. Ass. U.K.* **41**, 59-68.

Bertrand, D.E.: 1977, 'Seasonal succession of the plankton of Penobscot Bay, Maine'. M.S. Thesis, University of Rhode Island, 108 pp.

Bousfield, E.L.: 1954, 'The distribution and spawning seasons of barnacles on the Atlantic coast of Canada'. *Bull. Natl. Mus. Can.* **132**, 112-154.

Bousfield, E.L.: 1955, 'Ecological control of the occurrence of barnacles in the Miramichi Estuary'. *Bull. Natl. Mus. Can.* **137**, 1-69.

Branscomb, E.S.: 1976, 'Proximate causes of mortality determining the distribution and abundance of the barnacle *Balanus improvisus* Darwin in Chesapeake Bay'. *Chesapeake Sci.* **17**, 281-288.

Crisp, D.J.: 1954, 'The breeding of *Balanus porcatus* (Da Costa) in the Irish Sea'. *J. Mar. Biol. Ass. U.K.* **33**, 473-494.

Crisp, D.J.: 1962, 'The planktonic stages of the Cirripedia *Balanus balanoides* (L.) and *Balanus balanus* (L.) from north temperate waters'. *Crustaceana* **3**, 207-221.

Crisp, D.J.: 1968, 'Differences between North American and European populations of *Balanus balanoides* revealed by transplantation'. *J. Fish. Res. Board Can.* **25**, 2633-2641.

Crisp, D.J. and Patel, B.: 1969, 'Environmental control of the breeding of three boreo-arctic cirripedes'. *Mar. Biol.* **2**, 283-295.

Deevey, G.B.: 1960, 'Plankton studies'. *Bull. Bingham Oceanogr. Coll.* **17**, 1-86.

Faber, D.J.: 1959, 'Studies on the biology of zooplankton of Narragansett Bay'. M.S. Thesis, University of Rhode Island, 131 pp.

Fish, C.J.: 1925, 'Seasonal distribution of the plankton of the Woods Hole region'. *Bull. U.S. Bur. Fish.* **41**,91-179.

Frolander, H.T.: 1855, 'The biology of the zooplankton of the Narragansett Bay area'. Ph.D.

Thesis, Brown University. 94 pp.
Gordon, C.M.: 1969, 'The apparent influence of salinity or the distribution of barnacle species in Chesapeake Bay (Cirripedia)'. *Crustaceana* **16**, 139-142.
Grave, B.H.: 1933, 'Rate of growth, age at sexual maturity, and duration of life of certain sessile organisms, at Woods Hole, Massachusetts'. *Biol. Bull.* **65**, 375-386.
Hines, A.H.: 1978, 'Reproduction in three species of intertidal barnacles from Central California'. *Biol. Bull.* **154**, 262-281.
Hulsizer, E.: 1967, 'Zooplankton of lower Narragansett Bay, 1972-1973'. *Chesapeake Sci.* **17**, 260-270.
Landau, M., Finney, C.M., and D'Agostino, A.: 1979, 'The barnacle *Balanus eburneus* Gould (Cirripedia) conditioned to spawn in the laboratory'. *Crustaceana* **27**, 241-246.
Lang, W.H.: 1977, 'The barnacle larvae of North Inlet, South Carolina (Cirripedia: Thoracica)'. Ph.D. Thesis, University of South Carolina. 179 pp.
Lang, W.H.: 1979, 'Larval development of shallow water barnacles of the Carolinas (Cirripedia: Thoracica) with keys to naupliar stages'. *NOAA Tech. Rep. NMFS Circ.* **421**, 1-39.
Lang, W.H.: 1980, 'Balanomorph nauplii of the NW Atlantic shores'. *Fich. Ident. Zooplan.* **163**, 6 pp.
Lang, W.H., Lawrence, S. and Miller, D.C.: 1979, 'The effects of temperatue, light and exposure to sublethal levels of copper on the swimming behavior of barnacle nauplii'. *In*, F.S. Jacoff (ed.). Advances in Marine Environmental Research. p. 273-289. Environmental Protection Agency Publ. EPA-600/9-79-035.
Londsale, D.J. and Coull, B.C.: 1977, 'Composition and seasonality of zooplankton of North Inlet, South Carolina'. *Chesapeake Sci.* **18**, 272-283.
Martin, J.H.: 1965. 'Phytoplankton-zooplankton relationships in Narragansett Bay'. *Limnol. Oceanogr.* **10**, 185-191.
McDougall, K.D.: 1943, 'Sessile marine invertebrates of Beaufort, North Carolina'. *Ecol. Monogr.* **13**, 323-374.
Moore, H.B., Albertson, H.D. and Miller, S.M.: 1974, 'Long-term changes in the settlement of barnacles in the Miami area'. *Bull. Mar. Sci.* **24**, 86-100.
Pratt, D.M.: 1965, 'The winter-spring diatom flowering in Narragansett Bay'. *Limnol. Oceanogr.* **10**, 173-191.
Reeve, M.R.: 1964, 'Studies on the seasonal variation of the zooplankton in a marine sub-tropical inshore environment'. *Bull. Mar. Sci. Gulf Caribbean* **14**, 103-120.
Weiss, C.M.: 1948, 'Seasonal and annual variations in the attachment and survival of barnacle cyprids'. *Biol. Bull.* **94**, 236-243.
Weiss, C.M.: 1948b, 'The seasonal occurrence of sedentary marine organisms in Biscayne Bay, Florida'. *Ecology* **29**, 153-172.
Zullo, V.A.: 1979, 'Marine flora and fauna of the Northeastern United States'. Arthropoda: Cirripedia. *NOAA Tech. Rep. NMFS Circ.* **425**, 29 pp.